What We Learned from JNCAP and Our Proposals

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ABSTRACT

This paper provides the results of JNCAP analyses and ongoing and future programs. The JNCAP presently conducts brake, full frontal and offset frontal impact, side impact and child seat safety performance tests. The overall evaluation based on three crash tests after 2001 has resulted in significant improvements in crashworthiness. This is mainly due to the improvement of the scores in offset frontal impact tests. The frontal impact test results show that cars are modified to have greater passenger compartment strength without changing the front stiffness. After side impact tests were implemented in 2000, the scores have improved every year. In side impact tests, the scores of injury criteria in particular were nearly perfect in 2002.

Research is under way conducted on pedestrian protection tests and child restraint abdominal injuries.

INTRODUCTION

The JNCAP (Japan New Car Assessment Program) has provided consumers with important information on the safety performance of new car models since 1996, when it began brake tests and full frontal impact tests for small cars [1]. The test items and test vehicle categories were step by step expanded based on accident analysis and amendment of safety regulations. In 2000, minicars were included in tests, and side impact tests were added. As of 2001, offset frontal impact tests were added, and overall evaluation have been introduced from calculating the combined scores based on three crash tests; full frontal, offset frontal and side impact tests [2]. At present, the JNCAP conducts brake tests, full and offset frontal impact tests, side impact tests, and child seat safety performance tests.

In this paper, the results of overall evaluation have been analyzed, and the factors which significantly affect the overall evaluation have been examined. Trends in car safety performance have been investigated using the JNCAP results since 1996. The effects of the introduction of offset impact tests were examined since they test different features of crashworthiness. Side impact tests were also analyzed based on the car deformation and door intrusion velocities. Current JNCAP research projects and future programs are summarized.

OVERALL EVALUATION

Evaluation Method

The JNCAP started overall evaluation as of 2001. The overall evaluations are calculated with weight average of the scores of full frontal, offset frontal and side impact tests (see figure 1). In each crash test, the score is given for individual human body region (full score in 4 points for each boy region) according to the sliding scale, and then the scores are weighted based on accident analysis. This weight in each body region in the full and offset frontal impact tests is head 0.923, neck 0.231, chest 0.923, lower extremities 0.923, respectively. In the side impact test, the weights are head 1.0, chest 1.0, abdomen 0.5, and pelvis 0.5. The full score in each test is 12 points. The overall driver score of 36 points is determined by adding up the scores for the full frontal, and offset frontal and side impact tests. Similarly, the overall front passenger score of 24 points is determined by adding the scores for the full frontal and side impact tests.

Analysis of Overall Evaluation

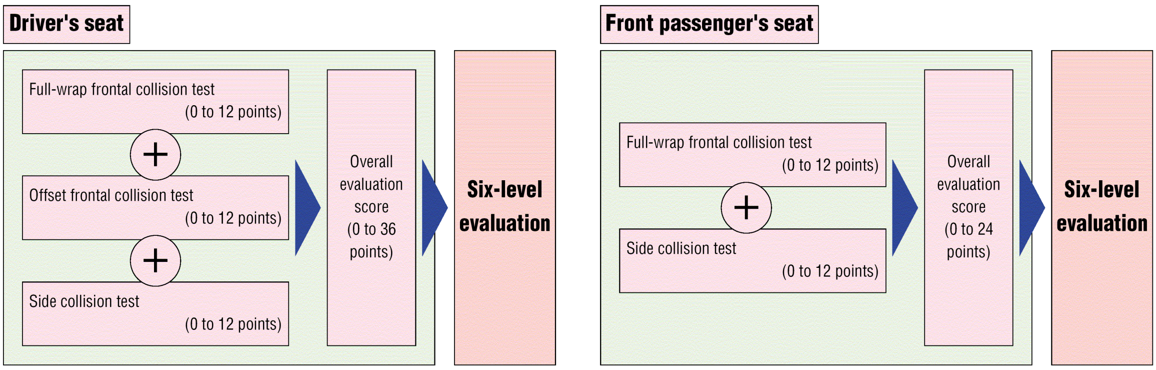
The overall evaluation scores of the driver and front passenger in 2001 and 2002 are shown in figure 2. The scores of the driver have improved significantly, especially for score for the offset frontal test. The change in the full frontal impact test score was small, possibly because the JNCAP started with the full frontal test and there was little room for improvement. The front passenger score has remained almost the same, whereas the score in the side impact test is improved. The front passenger score in the offset frontal test is not included in the overall score; the average score in 2001 was 10.53 points against 9.88 points in 2002.

	Injury value	Points (a)		Degree of body deformation	Points (b)		Weight (c)		Overall points ((a) + (b)) x (c)
Head	Head injury criterion (HIC)	0 to 4 points	+	Steering wheel upper displacement	0 to -1 point	×	0.923	=	0 to 3.692 points
Neck	Tensile load Shearing load Moment of extension	0 to 4 points (the lowest value is chosen)	+	(none)	—	×	0.231	=	0 to 0.924 points
Chest	Resultant chest acceleration Chest displacement	0 to 4 points (the lowest value is chosen)	+	Steering wheel lower displacement	0 to -1 point	×	0.923	=	0 to 3.692 points
Legs	Femur load (lower value of left and right) Load on Tibia index (lowest value)	0 to 2 points 0 to 2 points	+	Brake pedal upper displacement Brake pedal lower displacement	0 to -1 point 0 to -1 point	×	0.923	=	0 to 3.692 points
									Total 0 to 12 points

(a) Full and offset frontal impact tests

	Injury value	Weight (a)		Weight (b)		Overall points (a)×(b)
Head	Head injury value (HPC)	0 to 4 points	×	1.0	=	0 to 4 points
Chest	Chest position	0 to 4 points	×	1.0	=	0 to 4 points
Abdomen	Total abdomen load	0 to 4 points	×	0.5	=	0 to 2 points
Pelvis	Pelvis load	0 to 4 points	×	0.5	=	0 to 2 points
						Total 0 to 12 points

(b) Side impact test



(c) Overall evaluation

Figure 1. Evaluation of JNCAP.

The average scores in each human body region for the tests are shown in figure 3. The score for the lower extremities in the full frontal impact test improved slightly. In offset frontal impact tests when comparing the results of 2001 and 2002, the scores of the chest and lower extremities have improved, thanks to better chest acceleration (score 1.81 to 2.46 points), and brake pedal displacement (deducting points 0.88 to 0.36). In side impact tests, the chest score is improving, and the scores in side impact have almost reached the full 12 points.

Figure 4 shows the trend in the combined probability of head, chest and femur injuries in the full frontal impact tests. In this probability, the injury severity of the head is AIS≥2, chest AIS≥3 and femur AIS≥2, respectively. The probabilities of chest injury were calculated from chest acceleration and deflection [2]. The injury probability was 70% in 1996, which was dramatically reduced to 37% in 2002, which demonstrates the effectiveness of JNCAP.

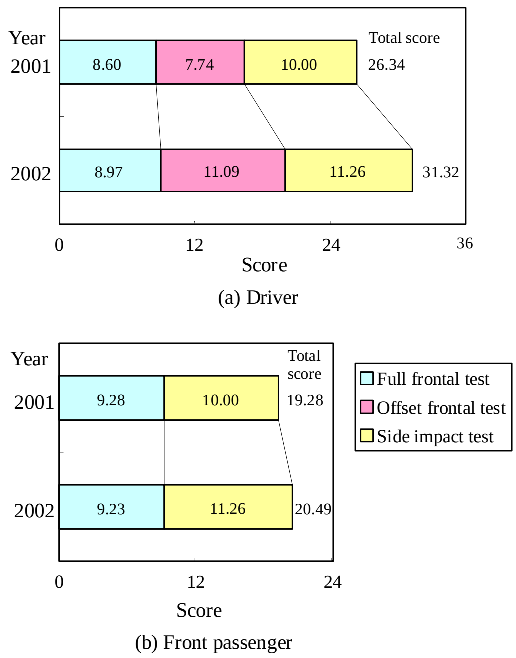
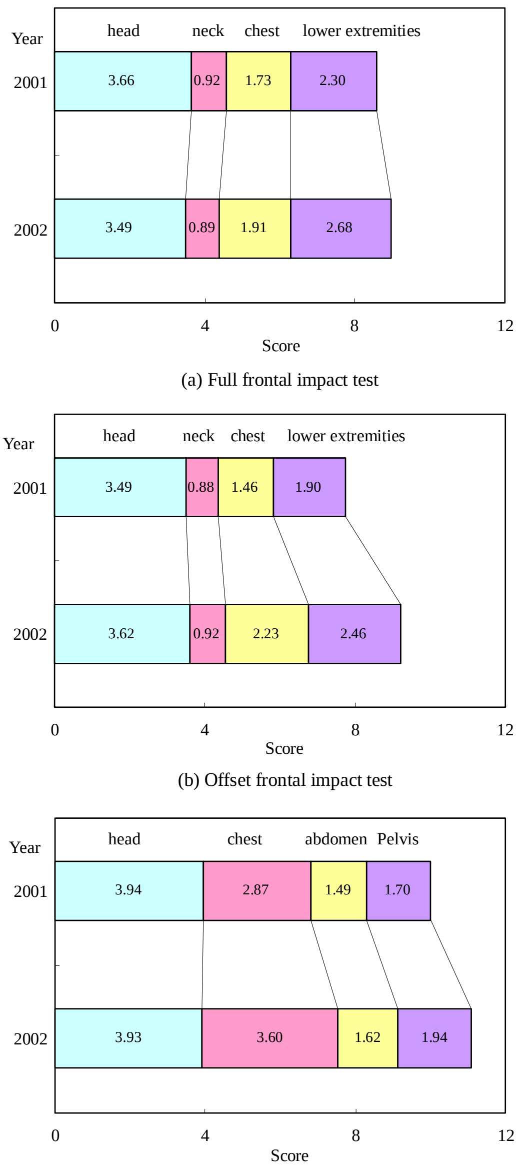


Figure 2. Average score in overall evaluation.



(a) Full frontal impact test

(b) Offset frontal impact test

(c) Side impact test

Figure 3. Average scores in full frontal, offset frontal and side impact tests by human body region.

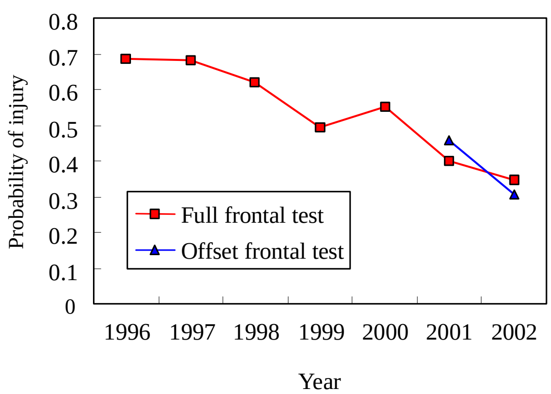


Figure 4. Combined probability of injury to head (AIS≥2), chest (AIS≥3) and femur (AIS≥2).

FRONTAL IMPACT TEST

Crashworthiness in Full Frontal Impact Tests

In full frontal impact tests, the vehicles are impacted with a rigid barrier at 55 km/h with full engagement of the vehicle front end. In the present investigation, the vehicle acceleration and force-deformation characteristics in full frontal impact tests were examined using the JNCAP data. The vehicle acceleration was determined from the average of both the left and right B-pillars to represent the acceleration of the passenger compartment. The acceleration-time histories of small cars are plotted in Figure 5. The maximum vehicle accelerations were from 300 to 450 m/s2, and the time durations from 0.075 to 0.110 s.

Figure 6 shows the force-deformation characteristics averaged by vehicle classes. The vehicle classes consist of minicar, small car, medium car, large car and multi-purpose vehicle (MPV) based on the JNCAP classification. The force was obtained by the products of car test mass and acceleration, and the deformation was from double integration of acceleration. The maximum vehicle deformations were about 0.6 m, except for the 0.45 m for minicars. Even in a full frontal test, the passenger compartment deforms in the later stage of the impact. The maximum force at this stage was 450 kN for a minicar and small car, 550 kN for a medium car and 650 kN for a large car.

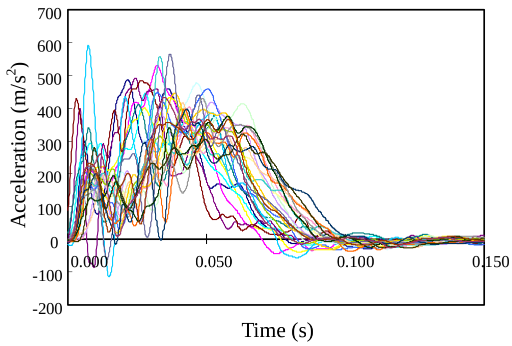


Figure 5. Acceleration time histories in full frontal impact tests (2002).

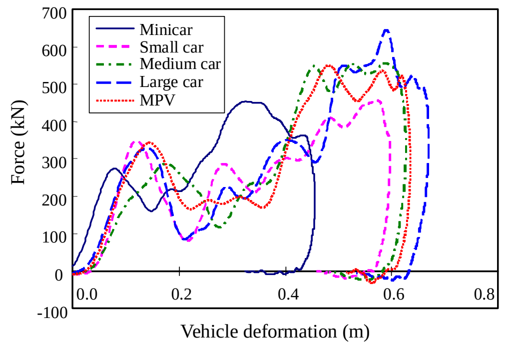


Figure 6. Average force-deformation characteristics in full frontal impact tests (2002).

Crashworthiness in Offset Frontal Impact Tests

The JNCAP has conducted offset frontal impact tests since 2001. In the test, the vehicles are impacted into the ECE R94 honeycomb at a velocity of 64 km/h with a 40% overlap ratio, the same as for the EuroNCAP test.

Vehicle accelerations were obtained from the average of both B pillars. Only longitudinal acceleration was considered because cars did not rotate significantly around the z-axis until they reached the maximum deformation point. Figure 7 shows the acceleration time histories. The maximum vehicle accelerations in offset frontal impact tests were 200 to 370 m/s^2, which were lower in range than those in full frontal impact tests. On the other hand, the time durations of offset frontal impact tests distributed from 0.120 to 0.150 s, relatively longer than those of full frontal impact tests.

The force-displacement characteristics in offset impact tests averaged by vehicle classes are shown in Figure 8. The displacement was determined from accelerometers, which reflects the sum of the deformations from the vehicle and the honeycomb in offset deformable barrier tests. The force-displacement curves were similar, irrespective of vehicle classes. The maximum vehicle displacement was 1.0 m for a minicar, 1.2 m for a small car, and 1.3 m for other vehicles.

These differences in acceleration and force-displacement characteristics indicate that full and offset frontal impact tests evaluate different features of crashworthiness with respect to acceleration and deformation.

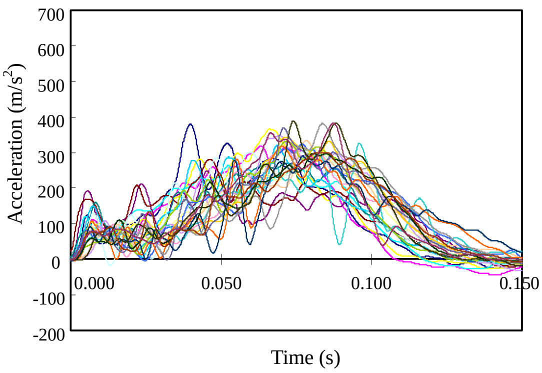


Figure 7. Acceleration time histories in offset frontal impact tests (2002).

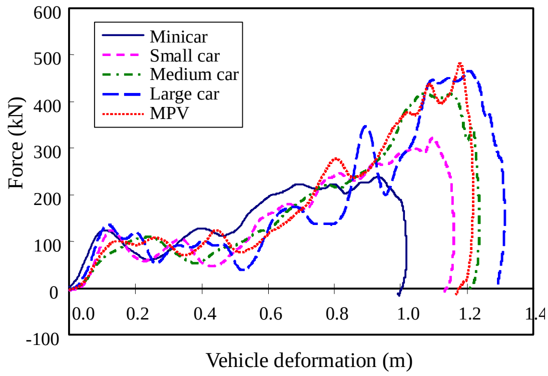


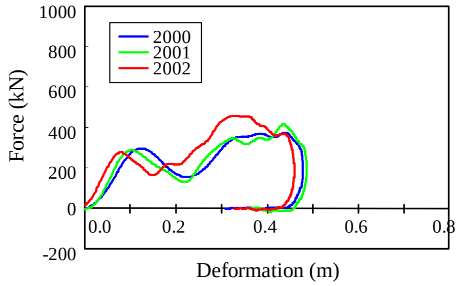
Figure 8. Average force-displacement characteristics by vehicle class in offset frontal impact tests (2002).

Trend in Force-DeformationCharacteristics

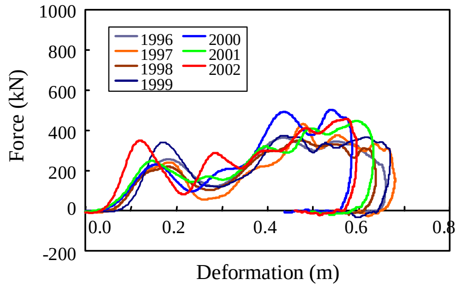
The influences of the introduction of offset frontal tests in 2001 were examined using the results of full frontal impact tests. The force-deformation characteristics in full frontal impact tests were compared by the test year. The force-deformation characteristics averaged for the year are shown in Figure 9. For small and medium cars for which a large number of models were tested, the force became high at a displacement of 0.4 m or more after 2000, compared with previous years. These results demonstrate that the strength of the passenger compartment of small and medium car tends to increase so as to prevent the collapse of the passenger compartment in offset tests. Since there were not so many MPV and large car test models, no clear tendencies in the force-deformation characteristics of these vehicles could be observed.

The differences in the force-deflection characteristics due to model changes were also examined. Figure 10 shows the force-displacement characteristics in full frontal impact tests for the car models tested more than once from 1996 to 2002. Car model A showed an increase in the initial force at a displacement of 0.15 m without any differences in maximum force. In car model B, there were no significant changes in the initial force, whereas the force increased in the latter stage of impact due to the great strength of the passenger compartment. The change in the force-deformation characteristic with this model is a general measure so that the intrusion can be reduced in an offset impact test.

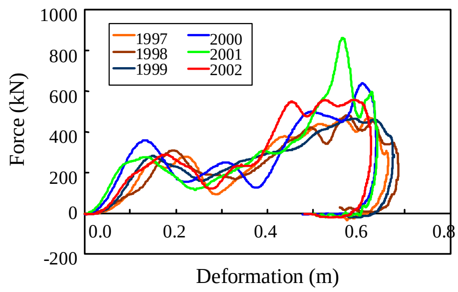
In car model C, the initial force was low though the maximum force became high. The low initial force can lead to the reduction of aggressivity. These results demonstrate that the introduction of offset frontal impact tests could not always cause the increase in aggressivity.



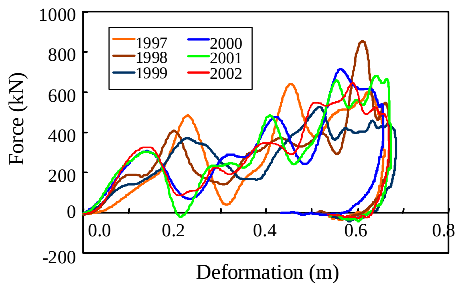
(a) Minicar



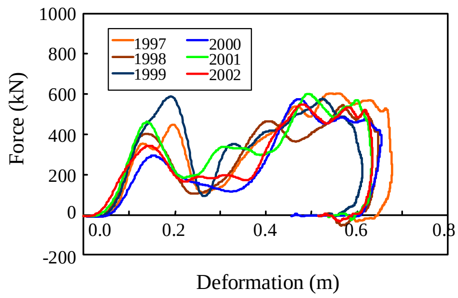
(b) Small car



(c) Medium car

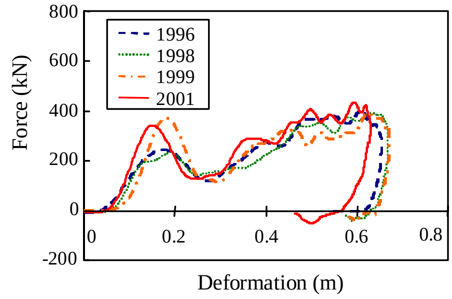


(d) Large car

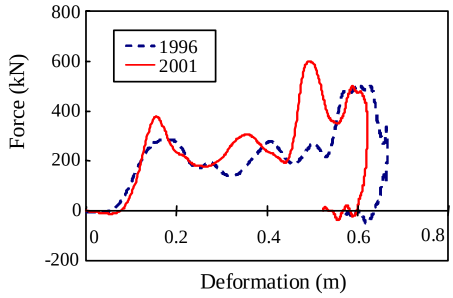


(e) MPV

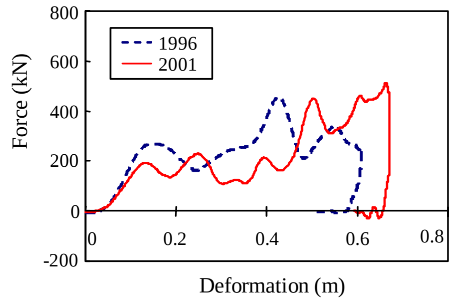
Figure 9. Trends in average force-deformation characteristics in full frontal impact tests by car class



(a) Car model A



(b) Car model B



(c) Car model C

Figure 10. Force-deformation characteristics in full frontal impact tests for car models A, B and C

Injury Criteria

Injury criteria and crashworthiness

The relations between injury criteria of driver dummies and vehicle deformation in full and offset frontal tests are shown in Figure 11. The HIC and chest acceleration decreased as the maximum vehicle displacement increased. Since the acceleration becomes lower as the maximum vehicle deformation increases, the acceleration-based injury criteria such as HIC and chest acceleration inclined to be small. Because of the honeycomb deformation, the maximum vehicle displacement in offset frontal impact tests was larger than those in full frontal impact tests. However, the results showed that the HICs and chest accelerations between in both the full and offset frontal tests reached similar levels. The data for the relation between vehicle acceleration and acceleration-based injury criteria are scattered, probably owing to the restraint system performance and curve shapes of the acceleration-time histories.

Figure 12 also shows that the intrusion-based injury parameters such as femur force and tibia index tended to be large with increasing of intrusion. The intrusion-based injury parameters are likely to be larger in offset tests than in full frontal tests. In offset frontal tests, the instrument panel intrusions were likely to be larger than those in full frontal tests, which led to higher femur forces. Tibia index increased with the toe board intrusion both for full and offset frontal impact tests.

Restraint system

With the introduction of offset frontal impact tests, the passenger compartment became stiffer. However, the acceleration-based injury criteria such as HIC and chest acceleration reported do not become worse; in fact such criteria have improved every year [1]. One of the reasons for these improvements is optimized restraint systems. In this research, the velocities of driver airbag deployment were investigated.

These velocities were determined based on the vehicle side-view in high-speed videos. The velocities were calculated by the distance from the steering hub to the driver chest, divided by the time from airbag deployment until driver chest contact. The results obtained using JNCAP 2001 and 2002 data are shown in Figure 8. The airbag deployment velocities were inclined to be high for minicars and small cars. Deployment in 2002 tended to be faster than in 2001. There were some cars in which the airbag deployment velocity was so high that the neck extension moments became large. As a result, despite the full scores for neck injury shown by most cars, there were a few cars in which the airbag deployment velocity was so high that the neck injury scores were not full.

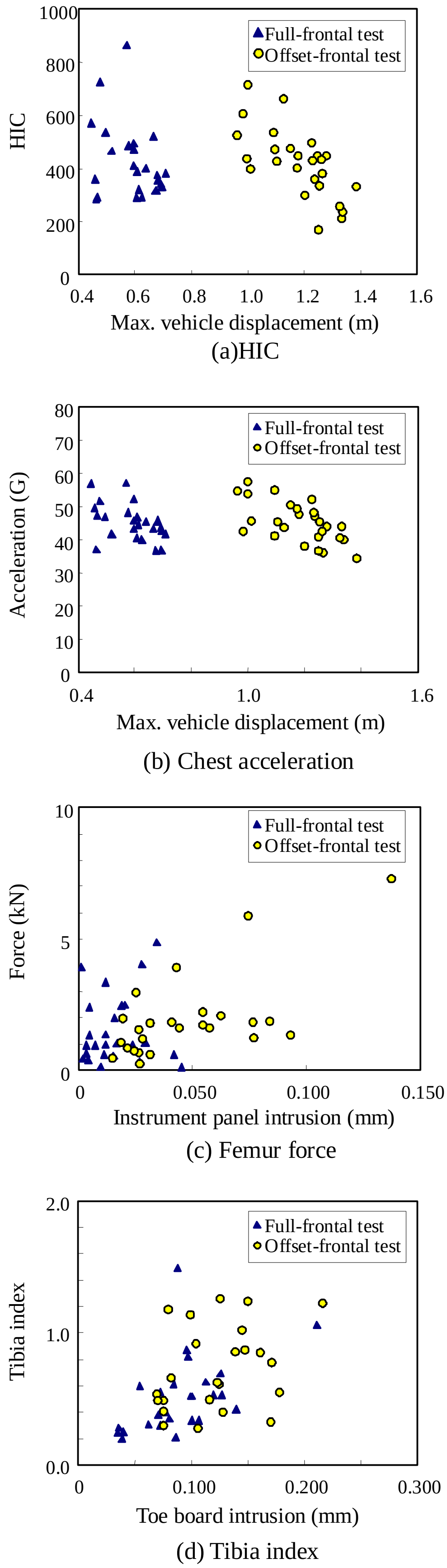
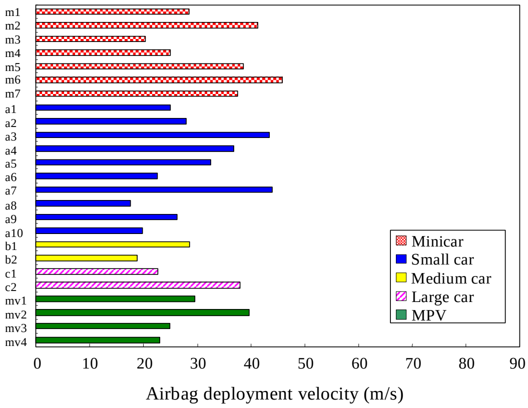
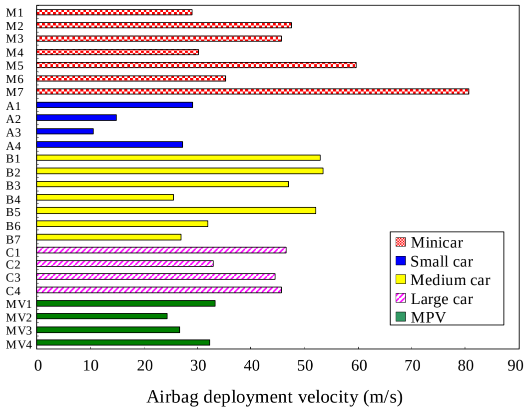


Figure 11. Injury criteria of driver dummies in full and offset frontal impact tests.



(a) 2001



(a) 2002

Figure 12. Deployment velocities of driver airbag for each vehicle model in offset frontal impact tests in JNCAP 2001 and 2002.

SIDE IMPACT TEST

The injury criteria in side impact tests were examined in terms of the door intrusion and impact velocity. The relation between the seat reference point (SRP) height and vehicle deformation at the corresponding SRP height are shown in Figure 13. The vehicle deformations tend to be small with the increasing height of SRPs.

Figure 13 shows the injury criteria of the dummy in terms of vehicle deformation and door intrusion velocity. The door intrusion velocities can be analyzed only for the data of 2000 where an accelerometer was attached at the B-pillar belt line. HPCs do not have a correlation with vehicle deformation. A slight correlation was found between door intrusion velocities and chest deflections. The abdominal and pelvis forces become high as the vehicle deformation at the height of SRP is larger. In addition to the vehicle deformation and intrusion velocity, padding and side airbag can also affect injury criteria in a side impact. The full score for the HPC, chest deflection, abdominal force and pelvis force is 650, 22 mm, 1 kN and 3 kN, then the most of test vehicles were near the full points.

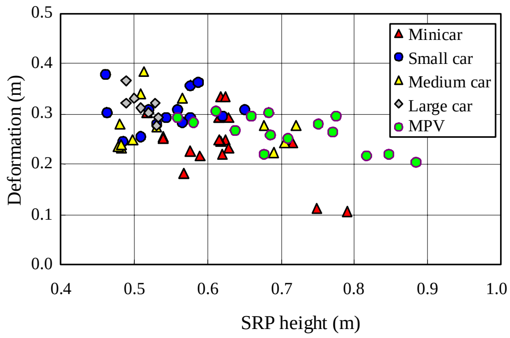


Figure 13. Height of seat reference point and vehicle deformation at this height level.

CHILD RESTRAINT SYSTEM TESTS

Child restraint systems (CRS) have been assessed since 2001. In 2001, 32 CRSs were tested. The injury risks by sled tests (acceleration corresponds to 55 km/h) and child seat usage are evaluated. Infant and child seats were tested in 2001. In a sled, the child seats are tested on a real car seat using a seat belt in a vehicle body. For infants tested in a rear-facing child restraint, the P3/4 dummy is used, and injury criteria such as chest acceleration, head projection, seatback angle during impact and seat damage are assessed. For children tested in a front-facing CRS, a Hybrid III 3YO is used, and the head excursion, head acceleration, chest acceleration and seat damage are assessed.

In some CRS tests, there was a concern that the CRS harness might penetrate the abdomen. However, this is difficult to judge using the current crash dummy sensors. Therefore, the measurement methods of abdominal forces or pressures are investigated. Baby carrycots will be tested in the near future.

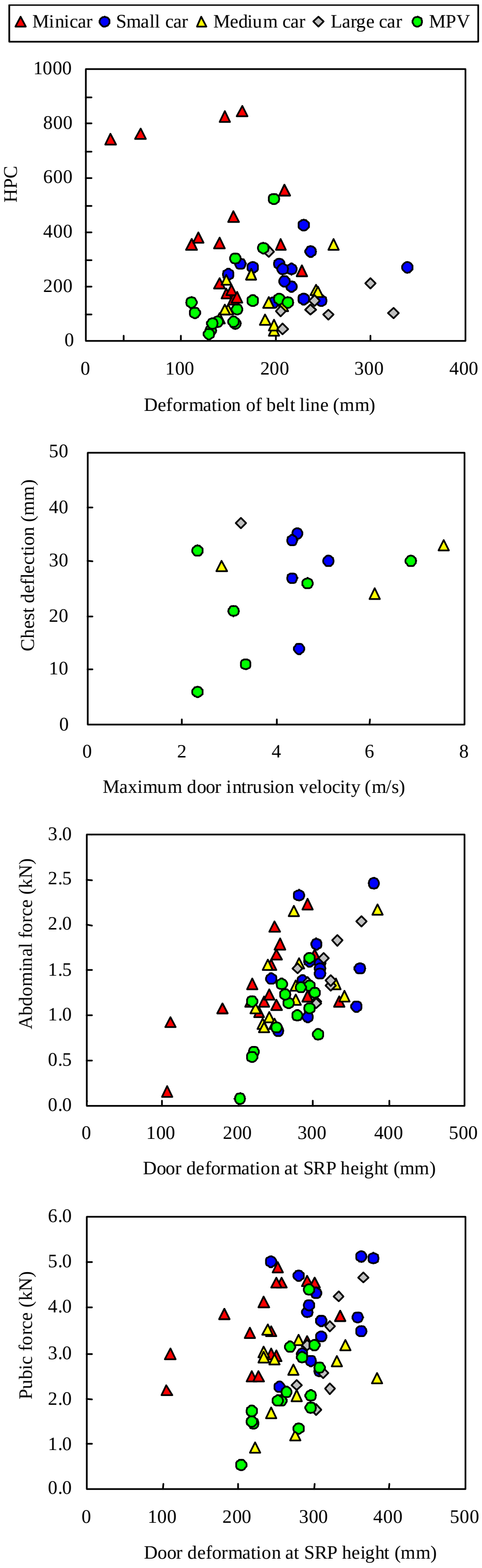


Figure 14. Injury criteria in side impact tests.

CURRENT PROBLEM AND FUTURE PROGRAMS

Frontal and Side Impact Tests

Overall evaluation started in 2001, and the car safety performance combined by full frontal and offset frontal and side impact tests have been evaluated. Scores of offset frontal tests and side impact tests have improved significantly. The injury criteria have decreased consistently since the start of JNCAP, and this trend has continued after introduction of offset frontal impact tests. For example, the combined injury risk to the head (AIS≥2), chest (AIS≥3) and femur (AIS≥2) in full frontal tests were 70% in 1996, and it decreased to 37% in 2002. Although offset frontal impact tests may possibly increase the stiffness of vehicle aggressivity, the JNCAP results showed high passenger compartment strength whereas the front stiffness remained at the same level.

After offset frontal impact tests were carried out, intrusion-based injury criteria such as the femur force and tibia index decreased because of the reduced intrusion into the passenger compartment. On the other hand, the high strength of the passenger compartment can induce high acceleration, which requires an effective restraint system generally provided by optimized restraint systems using a seat belt and airbag. High-speed video analysis showed that the airbag deployment velocities for some cars became higher. Further analysis will be expected, since this high deployment airbag velocity or pressure can increase the injury risk to OOP (out of position) and small occupants.

The self protection of the vehicle has improved significantly, thanks to the full and offset frontal impact tests. Compatibility will be an important issue in vehicle performance in the next stage. In full frontal impact tests, the high-resolution load cells (150 mm x 150 mm) have been attached on the rigid barrier, and the force distributions are measured for research purposes.

In side impact tests, the injury criteria have been decreased by the side stiffness, B pillar layout, door pad, and airbag. As a result, the side impact score have improved, and the HPC, chest deflection, and pelvis force showed nearly full scores. The scores in the side impact test have become better as the ground height of the seat reference point has become greater, e.g., the MPV due to the height relation between the MDB barrier face and the seat reference point.

Since in MDB tests, the contact of the dummy head does not occur in most cases, the risk of head injury which has been frequently observed in real side collisions is difficult to evaluate. Some cars have a new head protection device like a curtain airbag. Therefore, pole impact and other tests should be introduced to evaluate these kinds of devices and head injury risk.

Pedestrian Protection Tests

In Japan, pedestrians account for about 27% of all traffic fatalities, and pedestrian protection is an important issue. The Japanese Ministry of Land, Infrastructure and Transport will introduce pedestrian protection regulation in 2005. The JNCAP is conducting research on pedestrian protection tests with plans to introduce them in 2003. The pedestrian protection test program will begin with the head impact tests which are based on a pedestrian protection regulation in Japan.

Comparison of JNCAP Scores with Real-World Accidents

The research to explore the correlation between JNCAP scores and real-world accident data has been carried out in order to show the effectiveness of JNCAP program. The results of the research will also provide a future indication of JNCAP.

CONCLUSIONS

As of 2001, JNCAP has started offset frontal impact tests, and overall evaluation is now been conducted on three tests; i.e., full frontal, offset frontal and side impact tests. There are also several projects currently under way.

1. The JNCAP overall evaluation scores have improved, mainly due to the scores in the offset impact tests. The chest acceleration and brake pedal displacement contribute to good scores on the offset frontal impact tests.
2. The acceleration is high in full frontal impact tests, and the intrusion is large in offset impact tests. Each test evaluates different features of crashworthiness. With the introduction of offset frontal impact tests, the strength of the passenger compartment has become greater, while frontal stiffness has remained at the same level.
3. Since the JNCAP came into being, the injury criteria in frontal and side impact tests have decreased every year. In full frontal tests, the combined probability of injury risk was 70% in 1996, against 37% in 2002. In side impact tests, injury criteria scores have nearly reached the full number of points except the abdominal forces.
4. JNCAP has a research program on CRS abdominal injury risk and pedestrian test.

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